

Cognitive Modeling and Task Analysis:
Basic Processes and Individual Differences

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Summary

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I. Introduction

This research project involves the continuation of two lines of theoretical and empirical research that have been of historical and current concern to the U.S. Air Force. The first line of research has been the determination of abilities that are of critical importance for the prediction of individual differences in skill learning, both at initial phases of training, and later on-the-job performance. This has been a central issue for selection, training, and classification purposes, even before formal the existence of a separate U.S. Air Force (e.g., the extensive work conducted by the U.S. Army Air Forces Aviation Psychology Research Program, under the direction of John Flanagan (see Flanagan, 1948; Guilford & Lacey, 1947; Melton, 1947). Over the past 50 or so years, efforts have been devoted to developing and validating taxonomic representations of cognitive and intellectual abilities. However, more research is still needed, given the complexity of human cognitive processes, and the limited resources that have been available for their investigation.

The second line of research, task and job demands, originally started by the same research group (e.g., Fitts), and is generally regarded as the beginning of Engineering Psychology. Specifically, the attention of psychologists during and after World War II represented a shift from "fitting the person to the job" to "fitting the job to the person" (McCormick & Sanders, 1982). The original impetus for this work was the high rate of aviation accidents that had been "determined" to be due to pilot error. Work by Paul Fitts and his colleagues determined that, in many cases, the design of cockpit displays and controls (especially the lack of standardization), was inherently incompatible with the limitations and capabilities of pilots -- especially under stressful combat conditions. Three-pointer altimeters could not be read accurately or rapidly, or identical control knobs could not be differentiated, except by taking visual attention away from the windscreen. Thus the information needed by the pilots for safe and effective operation was frequently unavailable or was available only in a degraded fashion. The approach to solving such problems has been one of analyzing both task requirements and the basic limitations and capabilities of the human operator.

These two lines of research come together when it is realized that the successful operation of a larger system (e.g., pilots, weapons officers, support staff, AWACS controllers, and so on), is determined by a constantly shifting interplay between the individual differences in abilities among the personnel, the amount of training provided, and the specific demands of the tasks that the personnel are called-upon to perform. Changes in the pool of applicants, such as a shift to higher or lower mean levels of abilities, impacts the importance of the selection and training systems. When the applicant population includes many more highly-talented individuals, selection systems become more important. Conversely, when the application population fails to deliver highly-talented individuals, more expense and effort is needed in the training system. There are, however, natural limits to these tradeoffs -- no amount of training, given extant methods and current success rates will develop an unqualified trainee into a fully skilled pilot or AWACS controller. In addition, task design interacts with both the selection and training functions. To the degree that intellectually demanding task components can be off-loaded or automated, the demands lesson for both selection and

training. However, history tells us that new technological developments have generally had the opposite path. *That is, new technologies typically increase the cognitive load on the operator, rather than decrease it.*

These considerations lead to the current project -- which focuses on basic research issues on the dimensions of task characteristics that determine cognitive load, and on the individual differences in ability dimensions that determine the likelihood of successful training and skilled performance. The research described in this report is just a small part of a larger effort by many researchers in the field of psychology. It draws on contributions from cognitive/experimental, engineering, educational, and differential psychology. A full historical treatment of this extensive literature is beyond the scope of this report, but it cannot be stressed too much that the work builds on a foundation that has been established by many others -- including several key researchers who previously worked for the U.S. Air Force over the past 50 years (e.g., R. L. Thorndike, P. Fitts, L. G. Humphreys, J. P. Guilford, J. Adams, E. A. Fleishman, R. Christal, P. Kyllonen, and many others).

II. Current Research

The goal of the current research program was to select a critical subset of task conditions and individual differences variables and evaluate the joint effects of these variables on task performance in a complex-skill environment. The subset of task conditions selected were those that involve basic processes of working memory, task monitoring, and differential loads on spatial reasoning and speed of perceiving and decision-making. The subset of ability determinants of performance included broad content abilities (spatial and math abilities), perceptual speed abilities (including complex perceptual speed, scanning, memory and pattern recognition). Measures of working memory ability were administered to evaluate whether additional convergence could be found between task component performance measures and individual differences predictors of performance. A complex task platform was adopted, which simulates many aspects of the job of an air traffic controller. Initial training was provided to familiarize trainees with the task, and to provide a baseline assessment of ability determinants of performance in each of the task components. Subsequent manipulations of task component demands and communication channel reliability were used to evaluate both overall effects (e.g., mean performance level differences) and moderating effects on ability - performance relations. The analyses of data from this study address the manipulation effects on both overall performance and on correlations between predictors and performance criteria. Implications of this research are discussed with respect to extant theory and empirical research. In addition, brief discussion is provided regarding the potential applications of these findings for operational environments.

Critical Abilities for Performance

In the current research project, and based on our previous AFOSR-sponsored research (Kanfer & Ackerman, 1990; Ackerman & Kanfer, 1996; Ackerman, 1999b), we have developed theory and conducted extensive empirical research with an aim toward developing a

useful classification of abilities that are critical for the prediction of individual differences in performance during and after skill acquisition. In concert with other U.S. Air Force research (e.g., Kyllonen, 1985, 1994; Woltz, 1988) and the extant literature on human abilities (e.g., see Carroll, 1993 for an extensive review), we have identified several key ability classes that have been demonstrated to have substantial validity for predicting individual differences in performance on skill-learning tasks. Each of these abilities is briefly discussed below.

General/Content Abilities. General intellectual abilities have perhaps the most substantial basis for predicting individual differences in learning tasks -- starting with the early research of Binet & Simon (1905) regarding the prediction of academic performance. Initial research and theory (e.g., Spearman, 1904) suggested that general intelligence was amorphous and indivisible. However, by the 1920s and 1930s, it had been clearly established that general intelligence was not all-encompassing in terms of either basic underlying individual differences (e.g., see Kelly, 1928; Thomson, 1939; Thurstone, 1938), or in terms of building optimal models for predicting performance in specific domains. So-called "group factors" or "content abilities" (e.g., spatial, math, verbal) were reliably found when large batteries of ability tests were subjected to factor analysis. Moreover, examination of these content factors revealed that validity in predicting individual differences in performance depended in part on a match between the content of the predictor ability and the content of the criterion task. That is, when trainees were required to learn highly-spatially demanding tasks or jobs, tests of spatial ability were generally more highly correlated with criterion task performance than were, say, verbal ability measures (e.g., see Guilford & Lacey, 1947).

It is possible to identify dozens of group factors, but as shown by Snow, Kyllonen, and Marshalek (1984), dividing the ability sphere into Spatial, Math, and Verbal abilities is a valid simplification for categorization purposes. In addition, this breakdown of the structure of abilities provides a simplifying scheme that can be adapted to particular broad-based prediction paradigms (when the researcher wishes to generalize beyond a narrow range of criterion tasks). We refer to these categories as content factors, because at least on a surface-level analysis of task requirements, the content of the tests describes the stimuli upon which the individual must work with to solve the test problems (i.e., words for Verbal content, figures for Spatial content, and numbers for Math content)

A final general ability has also been subjected to a great amount of discussion in the past 10 years or so. In one framework Working Memory (a construct from the experimental psychology literature) can be thought of as attentional capacity (e.g., see Baddeley, 1986). Recent discussion has also portrayed working memory as essentially the same thing as reasoning ability -- which is central to the conceptualization of general intelligence (over and above respective content abilities), see Kyllonen & Christal (1989, 1990). Working Memory has been implicated as critical for predicting individual differences in task performance, especially on complex tasks. As such, a consideration of Working Memory, as a supplement to the content factors will be incorporated into the empirical study described below.

Perceptual Speed Abilities. Previous research in our laboratory has demonstrated that perceptual speed abilities may provide a critically important supplement to measures of general and broad content abilities, in the prediction of individual differences in performance during skill acquisition (e.g., Ackerman, 1988; 1990; 1992; Ackerman & Kanfer, 1993; Ackerman, Kanfer & Goff, 1995). According to Ackerman (1988), Perceptual Speed (PS) is defined as: "In the language of skill acquisition, individual differences found on [perceptual speed] tests are directly attributable to the speed with which these productions can be implemented and compiled (e.g., see Werdelin & Stjernberg, 1969). (p. 190)" It turns out that a more extensive analysis of extant measures of PS ability suggested that the tests could be taxonomized on a number of (overlapping) dimensions, based on an information-processing analysis of test content. A previous analysis (Ackerman & Rolhus, 1996) suggested the following candidate dimensions of underlying test demands: (a) Content (spatial, verbal, numerical), (b) Consistency (consistent information processing or varied information processing); (c) Novelty (familiar vs. novel stimuli); (d) Precision (of encoding and of responding); (e) Modality (of encoding and of responding); (f) Memory demands (low vs. high), (g) Scanning vs. single items.

While it would be theoretically possible to create a completely-crossed sampling of tests for these seven dimensions, the exponential number of tests that would be generated make for an impractical empirical evaluation (especially inasmuch as tests could also combine dimensions -- such as a test that had mixed spatial and verbal content). Instead, in a study now submitted for publication (Ackerman & Cianciolo, under review) we attempted to sample broadly from most of these dimensions, in the hope that patterns of consistent individual differences would emerge, inductively, across the various dimensions. In all, we adapted or created 15 tests of PS abilities, to administer along with 6 extant measures of PS abilities, 12 tests of content abilities (verbal, spatial, numerical), and a set of Choice and Simple RT measures.

By subjecting the PS tests to a factor analysis, we established that there is a general PS factor, but there were also three lower-order PS factors that were clearly differentiable in terms of the information processing demands of the tests. Specifically, one factor was dominated by tests that involved recognition of simple patterns (e.g., Canceling Symbols and Finding \in and \forall) -- which we designated as **PS-Pattern Recognition** (abbreviated PS-Pattern). A second factor involved scanning, comparison, and look-up processes (e.g., Name-Comparison Test and Number Comparison Test), which we designated as **PS-Scanning**. The third factor was best identified as making substantial demands on working memory (e.g., Digit/Symbol, and Coding tests). We identified this factor as **PS-Memory**. A complete representation of PS ability also includes an additional PS factor identified in previous research (called **PS-Complex**, because the tests involve both traditional PS and additional cognitive components, such as spatial ability and estimation/interpolation, and heightened working-memory loads; see Ackerman, Kanfer, & Goff, 1995). This factor structure was replicated in a later study (also reported in Ackerman & Cianciolo, under review).

Based on our research, these four PS factors (PS-Complex, PS-Memory, PS-Pattern, and PS-Scanning) have differential associations with task performance across skill acquisition trials. Some (e.g., PS-Complex and PS-Memory) are especially important in accounting for individual differences in performance on complex skill tasks, while others (PS-Pattern and PS-Scan) are more important in accounting for individual differences in performance on simple skills.

Psychomotor Abilities. Although not considered for the empirical study to be described below, our research has shown that there psychomotor ability measures can also provide incremental predictive validity for individual differences in skilled performance -- especially for tasks that are routine and proceduralized (see, e.g., Ackerman & Cianciolo, 1999; under review). Ability factors for Tapping, Mirror and Maze Tracing, and for Serial Reaction Time have been reasonably well established as useful predictors after extensive task practice. Most of these ability measures are not regarded as useful for predicting performance for tasks of high complexity, and there was no a priori reason to expect that these abilities would be sensitive to the kinds of information processing load manipulations under study in this project. However, for future research on less complex tasks -- consideration of psychomotor abilities is certainly warranted.

Development of the Experimental Protocol

Training Phase. The main goal for the training phase was to provide trainees with a reasonable amount of experience and practice on a complex skill-learning task -- one that makes substantial demands on the critical abilities outlined above (namely, content abilities, working memory, and at least some of the PS abilities). The training phase should also provide for, after practice, relatively stable correlations between the ability predictors and measures of task performance. The underlying criterion task also was required to have several performance components, that could be distinguished, both in terms of mean levels of performance (e.g., based on the respective information processing requirements of the task components), and in terms of ability-performance components (i.e., differential correlations between constellations of ability predictors and component task performance). The Terminal Radar Approach Controller task (TRACON®) provided an excellent test-bed for our purposes. The task is sufficiently complex that skilled performance develops only after an initial instruction period, followed by 8-15 hours of task practice. Moreover, there are three differentiable task components embedded in the task -- namely handling overflights, departures, and arrivals.

“Overflights” are planes that enter and exit the operator’s airspace at cruising altitudes. Trainees are required to acknowledge these airplanes as they approached a boundary Very high frequency omnidirectional range station (VOR) fix, monitor progress through the sector, and handoff to a Center controller. “Departures” are planes that originate at one of the four airports, climb to a cruising altitude and are to be handed off to a Center controller. Operators are required to release departures from airports, evaluate and remediate potential conflicts as the planes climb to a cruising altitude and turn to intercept their intended flight

paths, and then handoff planes to the appropriate Center controller. "Arrivals" enter the operator's airspace from one of the boundary VOR fixes, and have to be landed at a designated airport. Operators are required to direct arrivals onto an appropriate heading and altitude to provide an acceptable handoff to the appropriate Tower controller, then these planes would land.

Extensive data on the TRACON task and the embedded task components have been collected and reported in the literature (e.g., Ackerman, 1992; Ackerman & Cianciolo, under review; Ackerman & Kanfer, 1993; Ackerman, Kanfer, & Goff, 1995). Overflights have been found to be the easiest task component. Correlations between PS measures and task performance are higher for this component than for the other two components -- mainly because the major demands on the trainee are to scan the display, monitor for conflicts and remember to hand-off the plane before it exits the controller's sector. Arrivals, on the other hand, have the highest amount of cognitive demands on the trainee. Concomitant with the differences in task-component difficulty (and differences in mean performance levels), differences in ability-performance correlations are found. Highest correlations with general, spatial, and math abilities are found for the Arrival component of the task, followed by Departures, and then Overflights. These differences in means and correlations provide an excellent means toward triangulating the effects of changes in task constraints.

Testing Phase. In order to assess effects of task demands on mean performance levels and on ability-performance correlations, one can change the constraints of the overall task, and/or change the constraints on the three task subcomponents. The approach adopted here was to parametrically change both sets of conditions. We settled on two manipulations with these goals in mind. The first manipulation was an overall task constraint change. By degrading the communication link between the controller and the pilots, we believed that we would increase several information processing demands on the trainee. The standard condition involves error-free communication between controller and pilot -- every command issued to a pilot is read-back without error and compliance is assured, unless the action is beyond the capability of the airplane. A degraded (or error-laden) communication channel introduces a stochastic parameter to the interactions between controller and pilot. A few examples may best illustrate this condition. In some cases, a command issued by the controller might not be heard by the pilot -- and thus no read-back is provided, and the plane does not comply with the instruction. In other cases, a command issued to one pilot may be misunderstood to be intended for another pilot. Under this scenario, a different pilot than intended will acknowledge the command, and comply with it. (The controller might instruct one plane to descend 5000 feet. Instead, that plane will continue on course, and another plane will descend 5000 feet.) In still other cases, a pilot will simply reply that he/she did not hear the message, and will request that the controller provide it again. In each of these cases, the controller has a substantially increased cognitive load (mainly in terms of having to monitor the communication channel, and also in terms of increasing the frequency of visually scanning the radar screen to make sure that new conflicts do not arise as a result of missed instructions or erroneous reactions to other commands).

The second manipulation involved changing the dominant components of the TRACON task without changing the overarching structure of the task. That is, in the training simulations, each simulation presented the trainee with 28 planes to handle -- 16 arrivals and 12 overflights and departures. By creating simulations that either focused on Arrivals or on Overflights, it was possible to change the respective demands on content abilities (e.g., spatial, math) and on perceptual speed abilities (especially PS-Complex and PS-Memory). Under the test conditions, an "Arrival" simulation had 20 arrival flights and no overflights. Under the "Overflight" test conditions, each simulation had 20 overflights and no arrivals. To provide additional measurements of performance, and to assess spill-over effects onto other task components, we filled-out each of the Arrival and Overflight simulations with 8 departures each. The test conditions were similar to the training conditions, in that both had 28 total planes to handled in a 30-min. simulation. The test conditions all had 8 departure flights, regardless of whether arrival or overflights were present in the simulations.

Method

Participants. Ninety-four adults participated. All participants were native English speakers, had normal or corrected-to-normal hearing, vision, and motor coordination. The sample had 38 women and 56 men, $M_{\text{age}} = 21.00$, $sd_{\text{age}} = 2.46$, range 18-30 years.

Apparatus. Pencil-and-paper testing (Session 1) was administered in a laboratory with prerecorded instructions and directions presented over a public address system. Up to 14 examinees were tested at a time. TRACON training and testing during Sessions 2-7 was administered on Dell and IBM Pentium computers with 17" monitors at individual carrels.

Ability Tests. Ability tests were selected on the basis of the taxonomy of critical abilities for task performance described above. Tests were selected to assess three broad ability factors (Spatial, Math, and Working Memory), and four narrow ability factors (PS-Complex, PS-Memory, PS-Pattern Recognition, and PS-Scanning). The factors and the constituent tests are presented below.

Spatial Ability

1. Spatial Analogy. This is a four-term analogy test (A:B::C:D) with spatial content.
2. Spatial Orientation. This is a test of three-dimensional visualization. Examinees are required to imagine a block figure, as seen from a different perspective.
3. Paper Folding. In this test, a two-dimensional projection of a piece of paper being folded in to different shapes is presented, then a hole is shown punched in the folded paper. The examinee's task is to visualize where the holes are made, when the paper is shown fully unfolded.

4. Verbal Test of Spatial Ability. This is a test of image generation and manipulation. Subjects are asked to close their eyes and imagine the items described verbally. Then they are asked a multiple choice question about the items in the image.
Example: It is morning and you are facing East looking at the sunrise. You walk forward for 100 yards, turn left, and after walking another 50 yards you turn about (i.e., turn 180 degrees). In what direction are you now facing?
a) North b) South c) East d) West

Math Ability

5. Math Knowledge. This is a wide range test of mathematical knowledge, from simple computation to algebra, geometry, and other advanced topics.
Example: What is the product of 16 and 10?
a) 1.6 b) .016 c) 160 d) 1600
6. Problem Solving. This is a test of math word problems.
Example: You are traveling at the rate of one mile per minute. What is your speed in miles per hour?
a) 10 mph b) 30 mph c) 60 mph d) 120 mph
7. Number Series. A test of inductive numerical ability. The examinee is presented with a series of numbers, and asked to indicate the next item in the series.
Example: 1 3 5 7 9 11 a) 11 b) 12 c) 13 d) 14

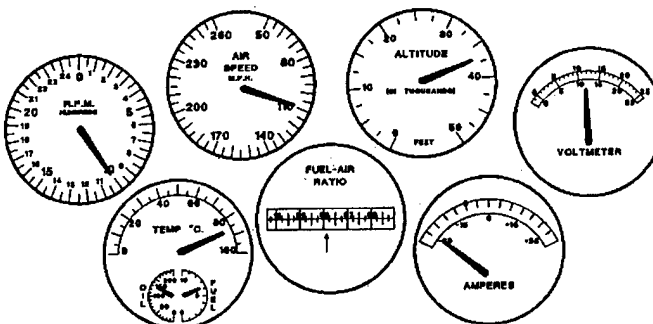
Working Memory Tests

8. Computation Span. In this test, examinees hear a series of simple equations (e.g., “3 + 2”). They are instructed to write the answer to each question. They are also instructed to keep a running memory of the second term in each equation. After a series of equations, the examinees write down the list of second terms for each equation in the series.
9. ABCD Order. This test presents a series of auditorially-presented sentences with order information regarding 4 letters (A, B, C, and D), and order information regarding sets of letters. The examinee must use the order information to place the letters in their appropriate order. Example: “A follows B.” “C follows D.” “Set 1 follows Set 2.” (The correct answer is: DCBA.)
9. Listening Span. In this test, there are three components to each item. The first part is the auditory presentation of a sentence. The second part is a visual presentation of a question about the sentence, which the examinee answers. After a series of sentences and questions are completed, the examinee completes the third part, which is to write down the last word of each sentence in the series.

Perceptual Speed Tests

PS-Complex Tests

1. Dial Reading Test.



	A	B	C	D	E
Temperature	87.	92.	8.5	91.	81.5

2. Directional Headings Test. In this test, the examinee must indicate the direction indicated by the three sources of information, or indicate if the information shows a conflict.

			(A) East	(B) South	(C) West	(D) North	(E) Conf.
(a)	N	↑ 360	=	=	=	X	=
(b)	N	↓ 360	=	=	=	=	X
(c)	W	← 270	=	=	X	=	=
(d)	E	→ 90	=	=	=	=	=
(e)	S	↑ 180	=	=	=	=	=

PS-Memory Tests

1. Coding. In this test, the examinee looks-up the a letter or two-digit codes for common words.

COLOR CODE	PRODUCT CODE
black C	chair 86
blue J	lamp 34
brown L	rug 73
green T	stand 52
grey M	stool 46
red F	table 92
yellow S	vase 27

Column 1	Column 2
brown M T X F C J S	rug 34 52 92 73 46 27 86
blue M T L F C J S	lamp 34 52 92 73 46 27 86
green M X L F C J S	stand 34 52 92 73 46 27 86
brown M T X F C J S	rug 34 52 92 73 46 27 86
grey M T L F C J S	stool 34 52 92 73 46 27 86
red M T L F C J S	table 34 52 92 73 46 27 86
black M T L F C J S	chair 34 52 92 73 46 27 86

2. Digit/Symbol Test. The examinee fills-in the numbers corresponding to the look-up key.

=	1	3	7	H	±	III	□	+
1	2	3	4	5	6	7	8	9

Write the correct number below.

+	=	□	H	7	□	3	H	1	□	=	1	3	□	=	7	=	3	□
9	1	8	5	4														

3. Naming Symbols Test. In this test, the examinee fills-in a single letter abbreviation for each of the symbols indicated in the look-up table.

□	△	○	◇	◇
r	t	c	d	p

○ □ □ ◇ ◇ □ △ ○ ○ △ ○ △ ◇ □ □ △ △ △ △
p r r p d c t p - - - - -

PS-Pattern Recognition

1. Canceling Symbols. In this test, the examinee searches through a page of symbols, and places a slash through the target symbols.

Begin here: Put a slash (/) through each □

2. Finding € and ¥. In this test, the examinee searches for the conjunction of two symbols, and circles each “word” that contains both symbols.

This is an imaginary language.
Circle every word that contains both € and ¥.

3. Finding a and t. In this test, the examinee circles words that contain both an ‘a’ and a ‘t’.

This is a foreign language.
Circle every word that contains both a and t.

carishe accademiche troveranno limitazione armonie nuovo clima
tanto nuovo regola vita nazionale oltre undici anni premi
fondazioni amministrazioni patrimoniali saranno voglia
fascisticamente regolati sono fierissimo essere stato autore
sollevamento dello prima ciliegia sollevamento rivoluzionario

PS-Scanning

1. Name Comparison. This test requires that the examinee check each pair of word entries, and indicate whether they are identical or whether they are different in any way.

John C. Linder X John C. Lender

Investors Syndicate = Investors Syndicate

2. Number Comparison. This test requires that the examinee check each pair of number entries and indicate whether they are identical or whether they differ in any way.

98765454 = 98765454
 456712 X 456713

3. Clerical Abilities - 2. In this test, the examinee looks-up corresponding information in a table and then uses a code to indicate the value in a list of names.

AVERAGE BALANCE				CREDIT RATING	
				Balance	Code
				\$ 999.99 or less	R
				1,000.00 to 1,999.99	S
				2,000.00 or more	T
				Name Missing	O

AVERAGE BALANCE				CREDIT RATING	
Adams, D. B.	\$8375.81	Carey, R. E.	\$6144.14	TAKE NAMES IN ORDER. BEGIN HERE.	
Adams, B. D.	1942.89	Clark, C. U.	318.89		
Allen, J. F.	287.45	Clark, C. V.	1731.43	1. Barnes, M. V.	<u>T</u>
Anderson, H. C.	1712.50	Cooper, B. L.	1135.58	2. Bosworth, A. G.	<u>O</u>
Andrews, C. L.	2130.38	Corbin, G. P.	985.23	3. Clark, C. V.	_____
Armstrong, C. P.	1543.37	Cosgrove, J. J.	1074.77	4. Botts, K. L.	_____
Atwell, C. R.	724.16	Coughlin, M. H.	2597.16	5. Andrews, L. G.	_____
Barnes, M. V.	5004.18	Cowan, P. L.	1374.04	6. Daly, L. E.	_____
Baxter, A. N.	384.82	Crane, N. D.	9418.21	7. Cosgrove, J. J.	_____
Bloomfield, H. T.	837.42	Dale, A. M.	954.16	8. Allen, J. F.	_____
Bosworth, A. P.	1822.77	Daly, L. E.	8914.67		
Botts, K. L.	187.16	Daniels, R. T.	2354.38		
Bronson, D. H.	4788.33	Deuborn, F. F.	1317.85		
Brown, J. R.	987.26	Decker, M. H.	983.22		
Brown, J. R.	1542.87		527.59		

TRACON Training Simulations. Each training simulation is comprised of 16 overflights and departures (with roughly equal frequency), and 12 arrivals. The planes request entry to the airspace at irregular intervals that are constrained to require the trainee to be always occupied with at least one active target. The trials are also constrained so that perfect performance (handling all 28 planes successfully) is just at the skill level achieved by subject matter experts. Each trial is concluded in 30 min. That is, in order to provide equivalent practice time across subjects, the trials are ended with time constraints, rather than waiting until all planes are handled -- which otherwise introduces a substantial variance in practice time.

TRACON Test Simulations. The test simulations were designed to be broadly similar to the training simulations, except for the specific requirements of the altered demands of the testing phase. That is, similar to the training simulations, all test simulations had a total of 28 planes to be handled. The trials were designed with the same constraints adopted in the training simulations (see Appendix). In the Arrival test simulations, though, no overflights were included. Instead, these simulations had 20 arrival flights, and 8 departures. In the Overflight test simulations, there were no arrival flights, but 20 overflights and 8 departures. That is, the simulations were designed to keep a common demand for handling departures, so that the performance on departure flights could be examined for spill-over effects from the other manipulations, across the Arrival and Overflight conditions.

The other test simulation manipulation, which was envisioned as a high vs. low working memory/monitoring manipulation, was a contrast between Perfect and Error-Laden pilot communications. The Perfect condition was analogous to the training simulations, where pilots always followed the operator's instructions (at least to the capability of the airplanes and the other controllers). For example, pilots would turn as instructed, and change altitudes and speed as instructed, but pilots would not comply with an instruction to reduce speed below "stall" speed. Also, controllers would not accept "handoffs" unless the airplanes were within radar contact. The following represent visual (in the Communications Box) and auditory (over the headset) examples of Air Traffic Controller (ATC) --Pilot communications in the Perfect condition (the ATC is represented as "App/Dep" for Approach/Departure Controller; the pilot responds with the call letters/number for his/her aircraft and a read-back of the direction):

App/Dep: N42A, Change altitude to 2000.
N42A: Descending to 2000.

App/Dep: CO445, Turn left heading 035.
CO445: Roger. Left to 035.

App/Dep: WN077, Cleared direct to DRABB.
WN077: Going direct to DRABB.

App/Dep: N782, Cleared for ILS approach, Contact tower at FAF.
N782: Thanks. Good day.

In the Error-Laden pilot communications, approximately 30% of issued commands resulted in a communication failure or a mis-communication. Below are examples of these sequences:

App/Dep: N23F, Turn right heading 295.

CO903: Roger. Right to 295.

[Note that the wrong plane acknowledged and followed this command]

App/Dep: N9OS, Change altitude to 2500.

WN077: Descending to 2500.

[Note that the wrong plane acknowledged and followed this command]

App/Dep: N9OS, Turn left heading 355.

N9OS: Repeat that. I was looking at a map.

App/Dep: N23F, Turn left heading 245.

N23F: Was that last command for me?

App/Dep: N23G, Turn right heading 325.

[No response]

App/Dep: N9OS, Turn left heading 360.

N9OS: Say again please.

App/Dep: N39L, Change altitude to 4500.

N39L: Your signal was weak. Say again.

Under these Error-Laden conditions, the operator must carefully: (a) listen to the read-back of the command, in comparison to the command issued; (b) review the communication box on the display for mis-matches in commands and readbacks; and/or (c) monitor the radar display for airplanes that are not proceeding as instructed.

By parametrically combining Arrival and Overflight simulations, and Perfect and Error-Laden conditions, it is possible to derive four separate testing sets:

1. Arrival - Perfect
2. Arrival - Error-Laden
3. Overflight - Perfect
4. Overflight - Error-Laden

It is important to keep in mind, though, that each of these test conditions also contained 8 departure flights. The departure flights had the same communication conditions imposed, to avoid having the participants simply choose an asymmetric tradeoff in favor of the easier departure flights.

Procedure. In Session 1, the battery of 21 ability tests was administered in a four-hour session, with 5-minute breaks provided after each hour of testing. Session 2 was devoted to a 70-minute instructional video for TRACON, followed by three 30-minute TRACON training simulations. Session 3 and Session 4 contained six 30-minute TRACON training simulations. Session 5 contained two 30-minute TRACON training simulations, followed by four 30-minute TRACON test simulations. Sessions 6 and 7 contained six TRACON test simulations each. Overall, then, there was 8.5 hr. of TRACON training (17 simulations), and 8 hr. of TRACON test simulations (16 simulations). The Test simulations represented a 2 x 2 x 4 within-subjects design (2 types of trials -- Arrival vs. Overflight; 2 types of communications, Perfect and Error-Laden, and 4 repetitions of each trial type). Both training and test simulations were administered in counterbalanced orders.

Results

Training Phase. The practice phase of TRACON proceeded in a fashion now generally well documented in our previous studies (e.g., Ackerman, 1992; Ackerman & Kanfer, 1993; Ackerman, Kanfer, & Goff, 1995). Mean performance and between-subjects standard deviations are shown for overall performance (number of planes handled in 30-minute simulations) in **Figure 1**. In addition, mean performance levels for the three components of task performance -- Arrivals, Overflights, and Departures -- are also shown in the lower panel of the figure. Performance starts off relatively poor, with an average of 8 planes handled in the 30-minute simulation. However, with practice, performance quickly improves, so that after 8.5 hr. of time-on-task, participants are, on average, handling nearly 20 planes. From the components-of-performance perspective, by the end of the training phase, the average participant is handling 60.3% of departures, 67.5% of arrivals, and 80.5% of overflights.

In order to smooth the data, and refine the total volume of data presented, performance scores were collapsed into six composite, or "session" scores. With the exception of Session 6, all sessions represent an average of 3 simulation trials. (Session 6 only contained the final two training simulation trails). Correlations between the 7 ability composites and TRACON performance, including overall and component measures, for each of the 6 sessions are presented in **Table 1**. In addition, the correlations among the ability composites are provided at the bottom of the table. Although there is a substantial amount of data in this table, there were several noteworthy findings. First, the prediction of overall performance was clearly increased from the first training session to the final training session for several abilities: Spatial, Math, PS-Complex, and Working Memory. In contrast, PS-Pattern showed negligible correlations with TRACON performance (consistent with the results obtained by Ackerman & Cianciolo, under review), and PS-Scanning showed significant and consistent correlations with performance across practice. Finally, PS-Memory showed declining correlations with practice -- again in accordance with previous, smaller-scale research (Ackerman & Cianciolo, under review).

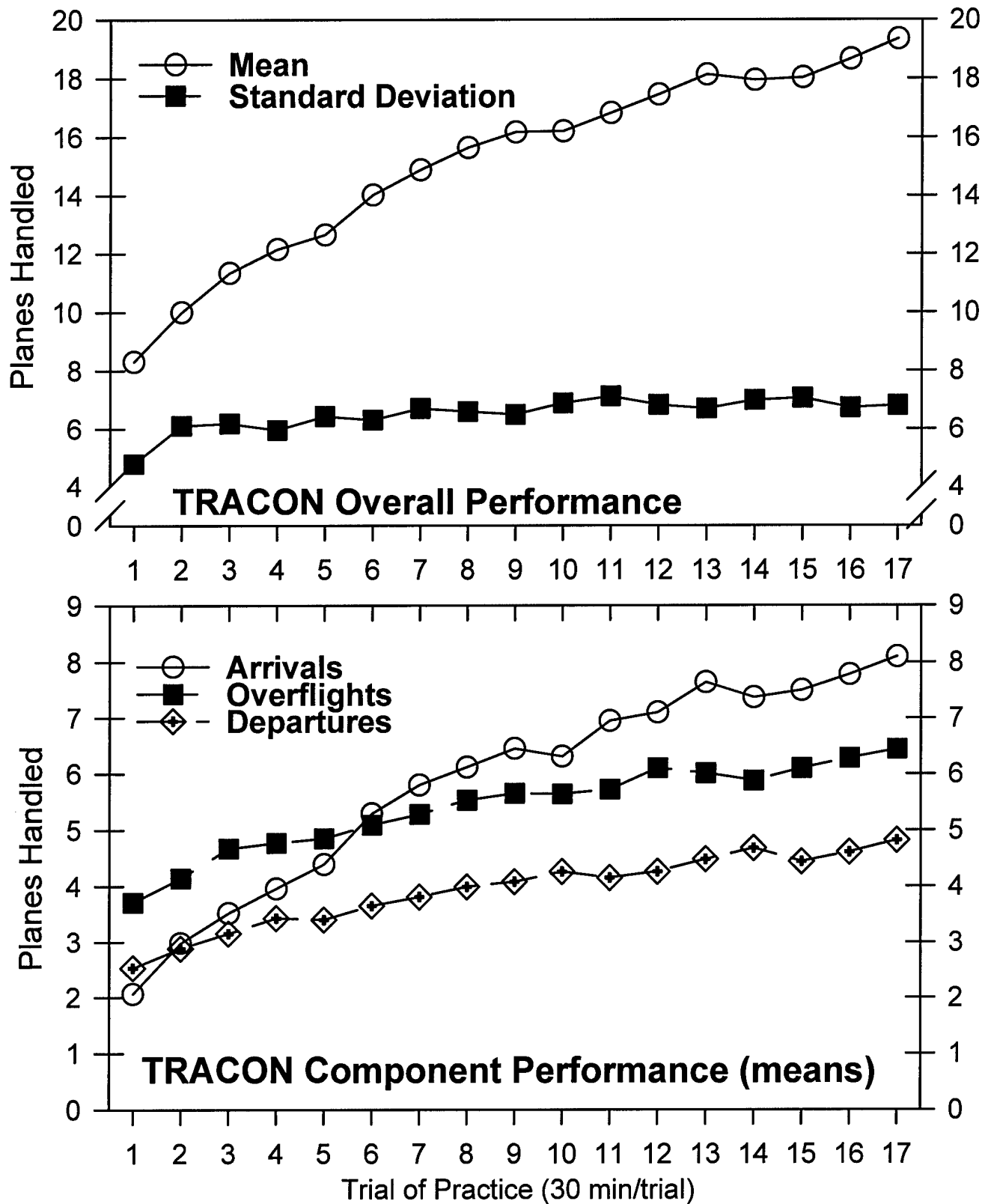


Figure 1. TRACON training phase performance. Upper panel: overall means and between-subjects standard deviations. Lower panel: Means by task component (arrivals, overflights, and departures).

Table 1. Correlations between Content, Perceptual Speed, and Memory Abilities and TRACON Training Performance (components and overall).

	Spatial	Math	PS Complex	PS Memory	PS Pattern	PS Scanning	Working Memory
Arrivals 1	.458**	.395**	.463**	.236*	.032	.240*	.260*
Arrivals 2	.588**	.500**	.524**	.205	.018	.271**	.396**
Arrivals 3	.688**	.589**	.588**	.214*	.063	.341**	.405**
Arrivals 4	.698**	.592**	.595**	.190	.082	.304**	.463**
Arrivals 5	.674**	.567**	.590**	.186	.143	.322**	.423**
Arrivals 6	.719**	.591**	.591**	.236*	.146	.304**	.481**
Overflights 1	.377**	.280**	.332**	.368**	.111	.231*	.316**
Overflights 2	.445**	.290**	.380**	.297**	.041	.233*	.343**
Overflights 3	.532**	.412**	.417**	.308**	.087	.295**	.433**
Overflights 4	.534**	.376**	.406**	.241*	.060	.248*	.287**
Overflights 5	.556**	.496**	.420**	.292**	.089	.270**	.338**
Overflights 6	.596**	.493**	.414**	.144	-.020	.218*	.337**
Departures 1	.422**	.312**	.338**	.406**	.057	.192	.281**
Departures 2	.439**	.394**	.416**	.346**	.031	.215*	.374**
Departures 3	.495**	.501**	.533**	.328**	.010	.272**	.397**
Departures 4	.441**	.495**	.445**	.238*	-.070	.231*	.331**
Departures 5	.402**	.424**	.423**	.267*	.009	.251*	.306**
Departures 6	.497**	.519**	.507**	.247*	-.019	.232*	.403**
Overall 1	.474**	.373**	.430**	.379**	.076	.251*	.324**
Overall 2	.585**	.476**	.526**	.313**	.033	.283**	.436**
Overall 3	.674**	.587**	.601**	.304**	.063	.352**	.466**
Overall 4	.657**	.574**	.571**	.244*	.037	.303**	.430**
Overall 5	.635**	.571**	.562**	.266*	.101	.325**	.416**
Overall 6	.700**	.614**	.586**	.242*	.058	.294**	.472**

Correlations among Ability Predictors

Spatial							
Math	.607**						
PS-Complex	.670**	.590**					
PS-Memory	.379**	.280**	.554**				
PS-Pattern	.187	.032	.338**	.492**			
PS-Scanning	.314**	.400**	.632**	.632**	.536**		
Working Memory	.489**	.545**	.554**	.414**	.124	.420**	

* $p < .05$; ** $p < .01$. $N = 94$

These patterns of correlations with overall performance were largely mirrored in the prediction of individual task components. As anticipated, given the more substantial processing and monitoring demands of the Arrival component, correlations between various ability measures and performance were larger for Arrivals than for either Overflights or Departures. In addition, the PS-Complex, PS-Memory, and Working Memory correlations with Overflights were smaller than the respective correlations with the Departure component, again in agreement with our earlier assertions regarding the decreased complexity of Overflights vs. Departures.

As shown in the lower part of the table, there is substantial common variance among the ability variables, as is generally expected. However, the correlations between the Working Memory composite and the other abilities is somewhat smaller than would be anticipated if, as claimed by Kyllonen and Christal (1990), working memory is synonymous with reasoning or general intelligence. In fact, with a general ability (g) composite formed from Spatial, Math, and PS-Complex composites, Working Memory only correlated $r = .608$, a substantial value, but certainly not indicative that working memory and g are substitutable variables. Given the controversy surrounding the degree of overlap between g and Working Memory, it is useful to examine the respective roles of these two composites on task performance. **Figure 2** shows the respective ability-performance correlations over TRACON training for the g and Working Memory composites. In each component of the task, the g measure provides a higher level of predictive validity than does Working Memory for TRACON performance. For Overflights, though, the correlations clearly diverge, with virtually stable correlations between Working Memory and task performance over training, but increasing correlations with g . (This divergence is seen in the previous table, showing the increasing correlations with between the constituent abilities (Spatial, Math, and PS-Complex) and Overflight performance.

Another way to evaluate the overlap between g and Working Memory in the predictive context is to conduct a series of multiple regressions. With Overall performance at initial and final training sessions, the two variables (g and Working Memory) together account for 27.9% of variance in TRACON Session 1 performance. If g is first entered into the equation, it accounts for 27.4% of the variance ($F(1,80) = 30.09, p < .01$). When Working Memory is added to the prediction equation, it only accounts for an additional 0.5% of variance, a non-significant effect ($F(1,79) = 0.60$). In contrast, if Working memory is first entered into the equation, it accounts for 13.0%. If g is subsequently added, it accounts for an additional 14.9% of the variance, a highly significant addition ($F(1,79) = 16.2, p < .01$).

For prediction of final training (TRACON Session 6), the difference between g and Working Memory as predictors is even more striking. Together, they account for 54.3% of the TRACON variance, but when first entered, g accounts for 54.0%, followed by Working Memory, 0.3 ($F(1,79) = .52$). In contrast, if Working memory is first entered into the equation, it accounts for 21.9%. If g is subsequently added, it accounts for an additional 32.4% of the variance, a highly significant addition ($F(1,79) = 56.1, p < .01$). From such analysis, it might be reasonable to conclude that *Working Memory is a lot less than g* . That is, all of the valid variance in the composite of Working Memory is subsumed in the composite of Spatial, Math, and PS-Complex abilities.

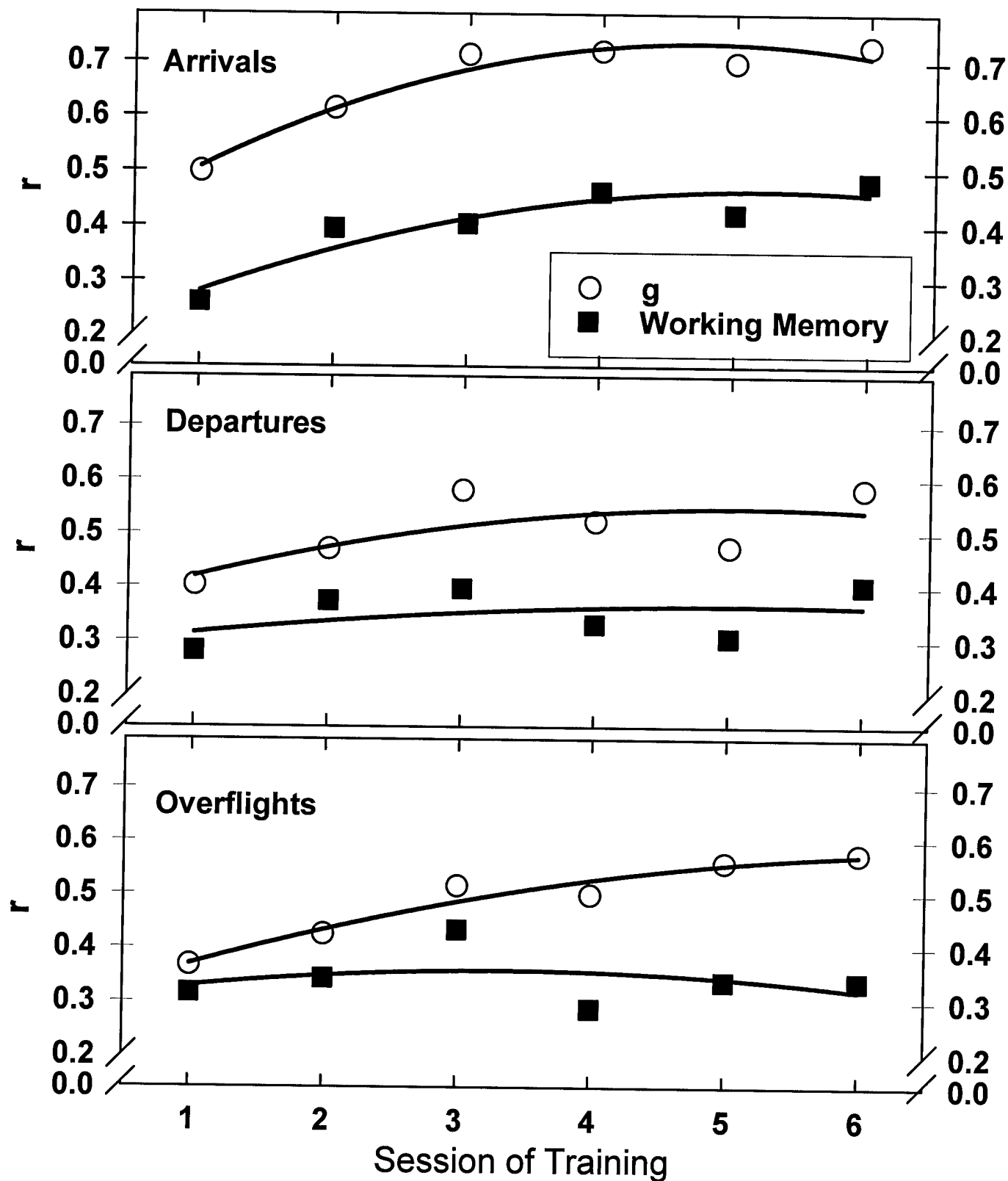


Figure 2. Correlations between general/content ability [g] and Working Memory composites and performance on TRACON over sessions of training practice. Lines indicate quadratic curve-fits.

Another perspective that can (and should) be taken on the training data, is to answer the question: 'How well can we predict individual differences in performance at final level of training?' Using the single *g* composite, 54.0% of individual differences variance in TRACON Session 6 performance was accounted for, substantially more variance than is accounted for by individual differences in initial performance (Session 1) on TRACON (40.1% shared variance between Session 1 and Session 6 performance indicators). Such results are consistent with Ackerman's (1988, 1989) theory of the ability determinants of skilled performance. The increasing correlation between *g* and task performance further refutes the Hulin, Henry, & Noon (1990, see also Henry & Hulin, 1987) claims of ubiquitous declines in predictive validity with task practice, ($r = .482$ vs. $.729$; $t(90) = 4.03$, $p < .01$). (See Barrett, Alexander, and Doverspike, 1992 for a more extensive critique of the Hulin, et al. position).

Summary. The preceding discussion supports three major points, as follows:

1. TRACON training proceeded as expected, in terms of practice effects for overall performance, and for performance components (i.e., arrivals, overflights, departures).
2. Performance on TRACON was well-predicted by several abilities, but a composite *g* variable provided an excellent accounting for performance, especially at the end of training, with 54.0% of interindividual differences variance in performance accounted for.
3. Working Memory, although significantly and substantially correlated with TRACON training phase performance, failed to account for any variance in performance over and above that accounted for by the general ability composite (*g*).

Testing Phase

In the testing phase of the study, trainees were subjected to 16 simulations, which made up a complete factorial within-subjects 2 x 2 x 4 design. The factors of the design were Arrival/Overflight (2 levels), Perfect vs. Error-Laden Communication (2 levels) and repetitions (4 simulations for each factor). The results of this portion of the study are presented in two sections: overall effects (e.g., means) and ability - performance correlations.

Overall Effects. Mean performance and standard errors of the means for the four test conditions are shown in **Figure 3**. The effect of Perfect vs. Error-Laden communication was clearly substantial for performance on the Arrival conditions ($\underline{M}_{\text{perfect}} = 14.39$, $\underline{M}_{\text{error-laden}} = 11.44$, $t(79) = 14.51$, $p < .01$). The effect of Perfect vs. Error-Laden communication for Overflight conditions was significant, though somewhat smaller ($\underline{M}_{\text{perfect}} = 17.75$, $\underline{M}_{\text{error-laden}} = 16.66$, $t(79) = 5.70$, $p < .01$), as anticipated. An analysis of the Departures for all four conditions showed, first of all, that fewer departures were handled under both Arrival conditions ($\underline{M} = 4.24$) than under the Overflight conditions ($\underline{M} = 5.87$), ($t(79) = -12.43$, $p < .01$). There was clearly a spill-over effect of the Error-Laden communication for the Departures task component under Arrivals ($\underline{M}_{\text{perfect}} = 4.80$, $\underline{M}_{\text{error-laden}} = 3.65$, $t(79) = 9.24$, $p < .01$). The effect of Error-Laden communication on Departures under Overflight conditions was essentially negligible ($\underline{M}_{\text{perfect}} = 5.86$, $\underline{M}_{\text{error-laden}} = 5.83$, $t(79) = -.27$, *ns*).

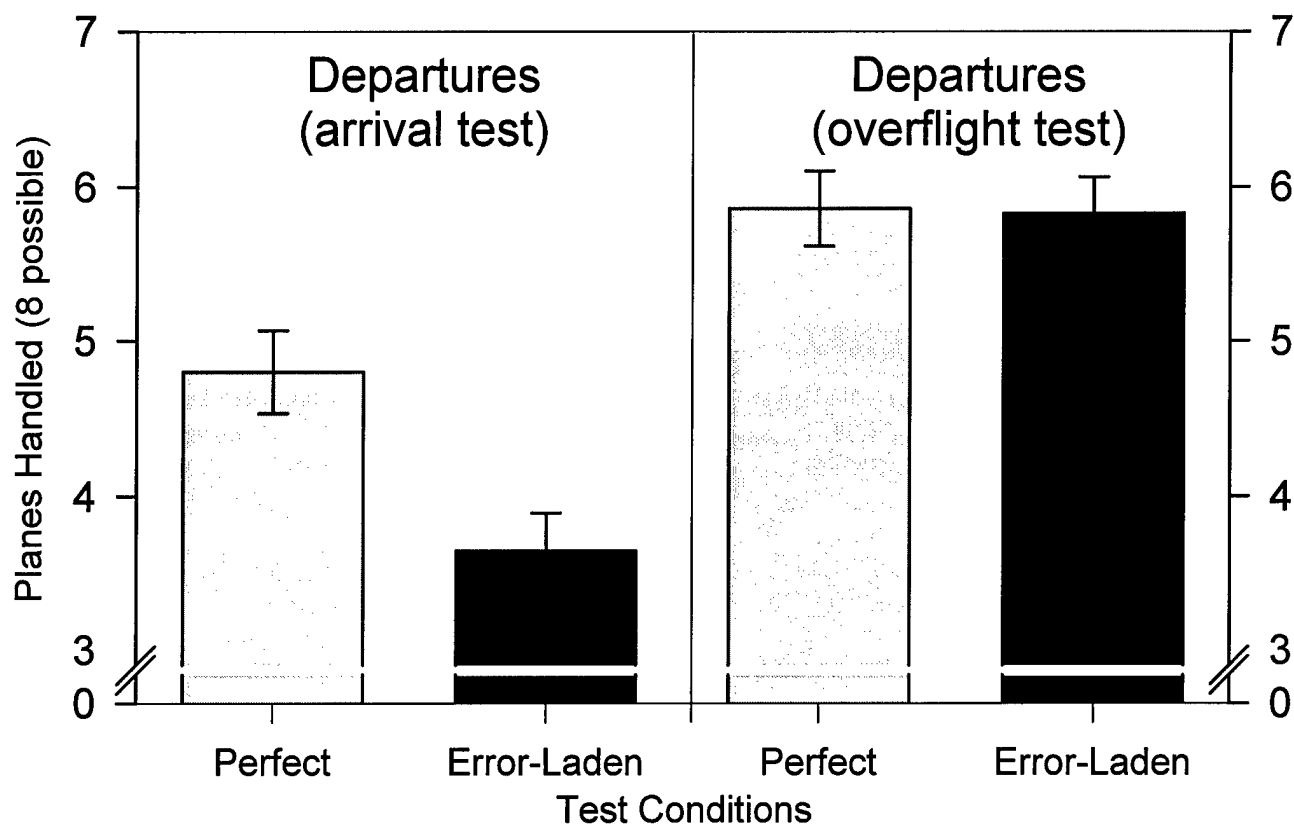
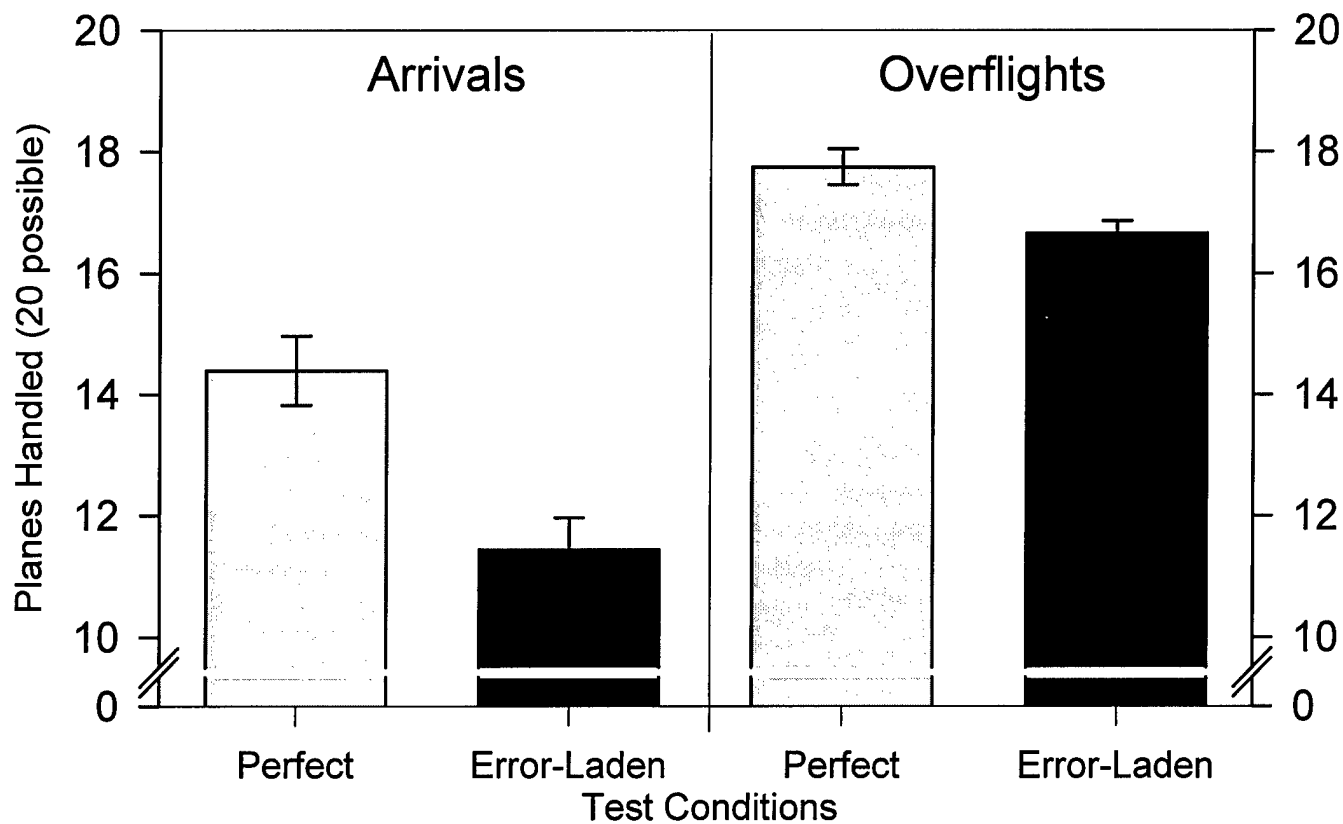


Figure 3. Mean performance on TRACON test conditions. Upper panel: Arrivals vs. Overflights. Lower Panel: Departures. Bars indicate 1 standard error of the mean.

In general the manipulations of Arrivals vs. Overflights had the desired effects on performance, as did the Perfect vs. Error-Laden communication. That is, as reflected in both the arrival and overflight planes handled, and the departure flights handled under the various conditions, the most difficult condition was (1) Arrivals-Error Laden, followed by (2) Arrivals-Perfect, then (3) Overflights-Error Laden, and finally (4) Overflights-Perfect. In fact, more planes [Overflights + Departures] were handled under the Overflights-Perfect condition than were handled in the final Training session ($M_{\text{Training}} = 19.01$ vs. $M_{\text{Overflights-Perfect Condition}} = 22.49$, $(t(80) = -8.87, p < .01)$, reflecting again that overflights are easier to handle than arrivals are.

Ability - Performance Correlations

Correlations between the 7 ability composites and performance under the four testing conditions are shown in **Table 2**, separately for the Arrival/Overflight performance conditions and the Departure performance components. In addition, tests for significant differences between the respective pairs of correlations were computed. Significantly correlations are shown by the arrows in the table (i.e., pairs with arrows are significantly different in magnitude from one another). Under Perfect communication conditions, only Spatial and PS-Complex ability composites showed significant differences between Arrival and Overflight conditions, with the larger correlations found for the Arrival conditions (as expected from the greater demands of handling arrivals). In contrast, significant differences were found for all 7 ability composites between Arrival and Overflight conditions under Error-Laden communications, again with the higher correlations for the Arrival conditions. Interestingly, although tending to show slightly higher correlations under the increased workload, neither the differences in correlations between the two Arrival conditions (Perfect vs. Error-Laden communication) nor the differences between the two Overflight conditions (Perfect vs. Error-Laden communication) were significant.

In contrast, only two of the 14 correlation comparisons for Departures were significant, a result not substantially different than one would expect by chance (given the per comparison $\alpha = .05$). Thus, even though mean performance on the Departure components clearly reflected the increased load on the Arrival component (see the mean performance levels in Figure 3), the abilities that determine performance on Departures did not increase in influence in tandem with the increased demands of the task overall.

How should one interpret these findings? At this point, the best representation is that large-scale changes in task demands (such as Arrivals vs. Overflights under Error-Laden communications) result in both mean performance differences and increasing demands on a wide array of abilities. (Indeed, even though PS-Pattern had minimal correlations with TRACON performance during training, at testing, the increasing load of error-laden communication brought a significant difference between the ability correlations with Arrivals and Overflights). Other manipulations, such as the effects of Arrivals vs. Overflights or Perfect vs. Error-Laden communications on Departures, produced mean performance effects, but virtually no significant differences in ability determinants of task performance.

Table 2. Correlations Between Ability Composites and TRACON Test performance.

	Spatial	Math	PS Complex	PS Memory	PS Pattern	PS Scanning	Working Memory
Arrival (A100)	.708**	.605**	.637**	.198	.104	.286*	.437**
Arrival (A70)	.733**	.623**	.648**	.272*	.140	.370**	.494**
Overflight (O100)	.532**	.483**	.364**	.087	-.019	.202	.317**
Overflight (O70)	.582**	.441**	.365**	.102	-.080	.197	.357**
Departures (A100)	.475**	.464**	.563**	.300**	.126	.367**	.397**
Departures (A70)	.442**	.436**	.540**	.357**	.097	.391**	.411**
Departures (O100)	.452**	.573**	.540**	.230*	.014	.282*	.436**
Departures (O70)	.445**	.538**	.495**	.236*	-.027	.290**	.476**

Notes: A = Arrivals, O = Overflights, 100 = Perfect Communication, 70 = Error-Laden Communication
 Arrows indicate pairs of significantly different correlations. *p < .05; **p < .01

Such results suggest that ability determinants of performance are substantially *more robust* than mean performance levels when manipulations of task difficulty are implemented. This is a critically important finding -- one that supports the speculations by Ackerman (1999) that it is the content of the task, rather than the degree of information-processing consistency or the degree of difficulty of the task that most affect the ability - performance correlations.

Summary and Conclusions

In this research project, critical task constraints (basic processes) and critical sources of individual differences (abilities) were identified and evaluated in the context of a complex skill-learning task. Initial training on the air traffic control simulation task (TRACON) established a baseline set of ability - performance correlation patterns. These patterns indicated that the task is well predicted by a tailored selection of general/content ability measures, perceptual speed ability measures, and working memory ability measures. By the end of practice, 54% of the between-subjects variance in performance was accounted for by a set of predictor measures administered prior to task practice. This predictability of performance from ability measures exceeded the variance accounted for by measures of initial task performance. Performance components (arrivals, departures, and overflights) showed different patterns of ability - performance correlations, in accordance with prior task analysis specifications of the basic processes that underlie each task component.

Test conditions were implemented that involved modification of the simulations to either place greater demands on spatial abilities (Arrivals vs. Overflights) or greater demands on working memory, task monitoring, and decision making (Perfect vs. Error-Laden communications). The test conditions demonstrated substantial changes to overall performance, in accord with the expectations of increased task processing demands. On the one hand, the manipulations had significant direct effects on several ability - performance correlations, also in accordance with theory and a priori predictions. On the other hand, the respective magnitudes of ability - performance correlations were quite robust -- indicating that even substantial changes in the task processing demands fail to fundamentally change the ability determinants of individual differences in task performance.

The data from the current investigation, in concert with other recent findings in the literature, suggest two major conclusions. First, properly selected ability measures are powerful predictors of individual differences in complex skill performance. The prediction of task performance can remain strong, even after substantial training and skill acquisition. Second, even though experimental psychology has introduced many variables that have an impact on mean performance levels (e.g., memory load), ability measures are robust predictors of individual differences in task performance -- even as the means and overall variability change. Broad content ability measures, for example, are more predictive of task performance than measures of elementary information processes, which presumably map directly onto task characteristics (e.g., see Ackerman, 199a; Kyllonen, 1985).

From an applied perspective, these findings add significantly to the corpus of literature regarding the generalization of validity of ability measures for predicting task and job performance. Even though these results do not necessarily support the notion that a single measure of general intelligence or working memory can be an optimal predictor of task performance, the results do imply that properly chosen ability measures can be used for applicant selection purposes within broader, rather than narrow, job classes. One domain of ability assessment that has been insufficiently investigated in the past five decades is that of perceptual speed abilities. The perceptual speed measures used in the current study and in other recent studies (e.g., Ackerman & Cianciolo, 1999) may offer an important supplement to extant measures of content and general abilities in situations similar to selection for entry-level technical jobs, such as those in the U.S. Air Force.

III. Personnel

The following personnel had significant involvement in this research effort:

Ackerman, Phillip L. - Principal Investigator

Kanfer, Ruth -- Senior Investigator

Rolfhus, Eric L. -- Research Associate

Beier, Margaret E. - Research Assistant

Cianciolo, Anna T. -- Research Assistant

Sierra, Edmundo -- Research Assistant

IV. Publications during the grant period and "in press"

Ackerman, P. L. (1998). Adult intelligence: Sketch of a theory and applications to learning & education, pp. 143-156. In M. C. Smith & T. Pourchot (Eds.) *Adult learning and development: Perspectives from educational psychology*. Mahwah, NJ: Lawrence Erlbaum Associates.

Ackerman, P. L., Kyllonen, P. C., & Roberts R. D. (Editors). (1999). *Learning and Individual Differences: Process, Trait, and Content Determinants*. Washington, DC: American Psychological Association.

Ackerman, P. L. (1999). Traits and knowledge as determinants of learning and individual differences: Putting it all together. Chapter in P. L. Ackerman, P. C. Kyllonen, & R. D. Roberts (Eds.), *Learning and Individual Differences: Process, Trait, and Content Determinants*. Washington, DC: American Psychological Association.

Ackerman, P. L. (1999). Adult intellectual development: Trait complexes and the world of work. *Proceedings of the British Psychological Society Organizational Psychology* (pp. 1-5). London, British Psychological Society.

Ackerman, P. L. (1999). Review of A. R. Jensen (1998). *The g factor: The Science of Mental Ability*. In *The Annals of The American Academy of Political and Social Science*, 563, 235-236.

- Ackerman, P. L., & Cianciolo, A. T. (1999). Psychomotor abilities via touchpanel testing: Measurement innovations, construct, and criterion validity. *Human Performance*, 12, 231-273.
- Ackerman, P. L., Cianciolo, A. T., & Bowen, K. R. (1999). Improving selection for psychomotor skills in dentistry. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 898-902.
- Ackerman, P. L., & Rolfhus, E. L. (1999). The locus of adult intelligence: Knowledge, abilities, and non-ability traits. *Psychology and Aging*, 14, 314-330.
- Cianciolo, A. T., & Ackerman, P. L. (1999). Touchpanel assessment of psychomotor abilities. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 624-628.
- Rolfhus, E. L., & Ackerman, P. L. (1999). Assessing individual differences in knowledge: Knowledge structures and traits. *Journal of Educational Psychology*, 91, 511-526.
- Ackerman, P. L. (In press). Domain-specific knowledge as the "dark matter" of adult intelligence: gf/gc, personality and interest correlates. To appear in *Journal of Gerontology: Psychological Sciences*.
- Ackerman, P. L., Beier, M. E., & Bowen, K. R. (In press). Explorations of crystallized intelligence: Completion tests, cloze tests and knowledge. To appear in *Learning and Individual Differences: A Multidisciplinary Journal in Education*.
- Venkatesh, V., Morris, M., & Ackerman, P. L. (In press). A longitudinal field investigation of gender differences in individual technology adoption decision making processes. To appear in *Organizational Behavior and Human Decision Processes*.
- Ackerman, P. L. (In press). A reappraisal of the ability determinants of individual differences in skilled performance. To appear in *Psychologische Beiträge*.
- Ackerman, P. L., & Cianciolo, A. T. (under review). Cognitive, perceptual speed, and psychomotor determinants of individual differences during skill acquisition. Submitted to *Journal of Experimental Psychology: Applied*.
- V. Presentations during the grant period
- Ackerman, P. L., & Rolfhus, E. L. (1998, April). *Knowledge structures and adult intellectual development*. Poster presented at the Cognitive Aging Conference, Atlanta, GA.

- Ackerman, P. L. (1998, August). *Aptitude complexes*. Invited paper presented at a symposium honoring the work of Richard E. Snow. American Psychological Association convention, San Francisco, CA.
- Ackerman, P. L. (1999, January). *Adult intellectual development: Trait complexes and the world of work*. Invited Keynote address presented at the British Psychological Society Organizational Psychology Conference, Blackpool, England.
- Ackerman, P. L. (1999, January). *Individual differences in knowledge: Relations with intelligence and implications for job performance*. Colloquium presented to the Institute for Work Psychology, University of Sheffield, England.
- Ackerman, P. L. (1999, April). *Adult intelligence and work from knowledge and trait complex perspectives*. Invited Master Tutorial presented at the Society for Industrial and Organizational Psychology, Atlanta, GA.
- Ackerman, P. L. (1999, June). *Learning and individual differences: Process and trait determinants*. Colloquium presented at: (1) the University of Melbourne, (2) University of Sydney, and (3) University of Queensland, Australia.
- Ackerman, P. L. (1999, June). *Management in the early 21st century: Workforce demographics and implications for high and low knowledge work*. Invited workshop address presented to the 3rd Australian Industrial and Organisational Psychology Conference, Brisbane, Australia.
- Ackerman, P. L. (1999, June). *Adult intellectual development: Trait complexes and the world of work*. Invited address presented to the 3rd Australian Industrial and Organisational Psychology Conference, Brisbane, Australia.
- Ackerman, P. L. (1999, July). *Knowledge, intelligence, and aging: A trait-complex approach*. Invited colloquium presented at the University of Mannheim, Germany.
- Ackerman, P. L. (1999, July). *Trait complexes among cognitive, affective, and conative constructs*. Symposium paper presented at the International Society for the Study of Individual Differences conference, Vancouver, Canada.
- Cianciolo, A. T., & Ackerman, P. L. (1999, October). Touchpanel assessment of psychomotor abilities. Paper presented at the 1999 annual meeting of the Human Factors and Ergonomics Society, Houston, TX.
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Appendix. Terminal Radar Approach Control (TRACON) Simulation Task

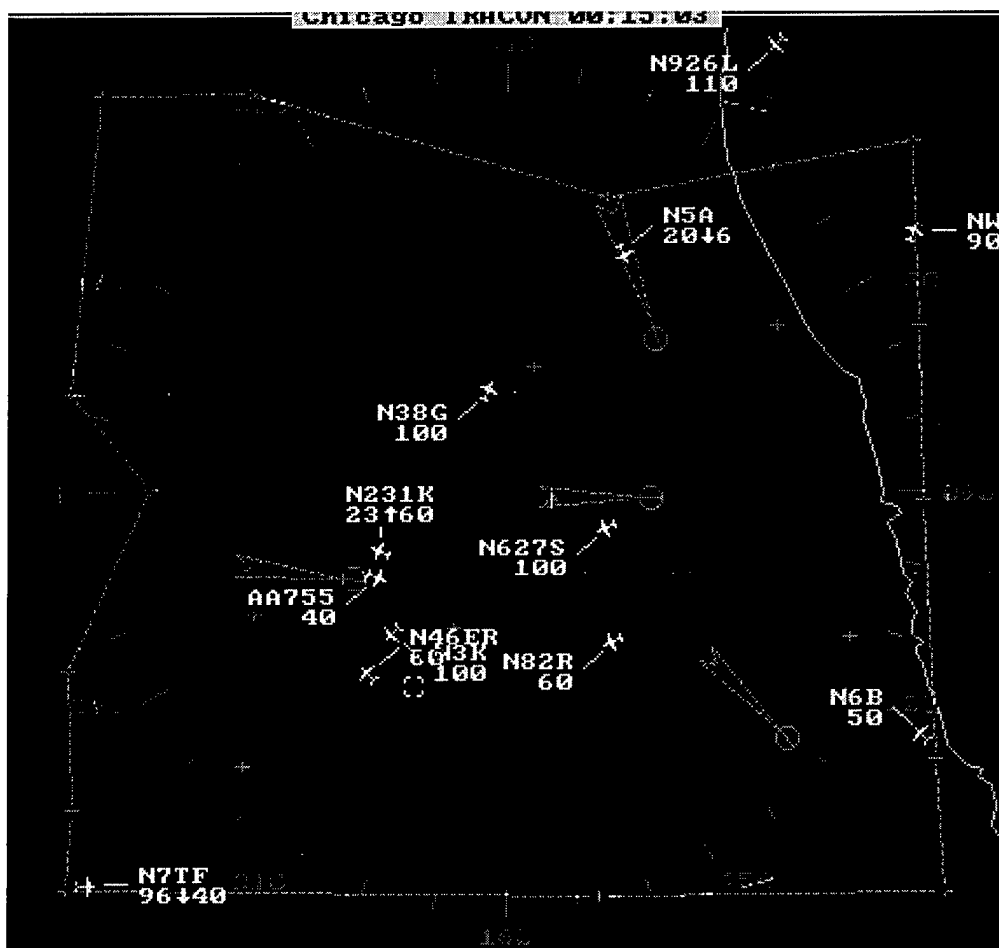
The task used for this research is a uniquely modified Professional version (V1.52) of TRACON simulation software, developed by Wesson International. Versions of this program have been, and are, in use in several locations in this country (including the FAA, NASA, DoD, and several colleges and university airway sciences programs) for training of air traffic controllers. Modifications for the current instantiation of the program allowed for the collection of a variety of data, described in more detail below.

Task analysis is a critical component of empirical investigation with any task, but especially with a complex task such as TRACON. In fact, one of the salient reasons for adoption of the TRACON task here is that there has been extensive historical work on task analysis for the full range of Air Traffic Controller tasks, including the subset implemented in TRACON. In particular, a five-volume set of task analysis materials has been prepared by the FAA (e.g., Ammerman, et al. 1987). Additional task analyses have been conducted by the U.S. Air Force, and by HumRRO (Means et al., 1988). All of these have been carefully studied in an effort to derive the critical components of the simulation task adopted for empirical evaluation.

The task requires that subjects learn a set of rules for positive air traffic control, including (a) reading flight strips, (b) declarative knowledge about radar beacons, airport locations, airport tower handoff procedures, en-route center handoff procedures, (c) plane separation rules and procedures, (d) monitoring strategies, and (e) strategies for sequencing planes for maximum efficient and safe sector traversal. In addition, subjects are required to acquire human-computer interface skills: including issuing mouse-based commands, menu retrieval, keyboard operations, and integration between visual and auditory information channels. Although the task represents a substantial reduction of rules and operational demands in comparison to the real-world job of an Air Traffic Controller (ATC), it represents an excellent simulation vehicle for study of skill acquisition, within a time-frame that can be handled in a laboratory-based research environment.

Display. TRACON presents the controller (subject) with a simulated color radar screen, depicting a region of airspace, radio navigational tower locations (VOR), airports, sector boundaries, and range rings. Planes are identified by an icon on the radar scope, with a data tag that indicates plane identification and altitude information. In addition, two sets of "Flight Strips" are presented at the right side of the display, a "Pending" and an "Active" set. Each flight strip contains information about a particular flight, including identification information, plane type, requested speed and altitude, and sector entry and exit destination information (See Figure A1). Finally, at the bottom of the screen is a "Communications Box" -- which shows commands issued to planes (and responses by the pilots), along with the controller's "score" for the current simulation.

When planes are about to enter the subject's sector (at a boundary or on the runway of an airport) this information is announced over the headset (e.g., "Northwest 123 ready for takeoff," or "Delta 123, with you, level at 9,000"). However, no flight is allowed to cross the sector boundary or take off from an airport without explicit authorization.



Generals	
ATC-32 D10 250k 90'	SHAWNEE BEBEE Ctr
IN06G1 C425 235k 60'	COMM DPA Twr
N926L PA46 220k 110'	OBK HINCK Ctr
N54PX C425 190k 40'	HINCK PARK Twr
N926L L23 250k 80'	THORN DEER Twr
NW89 L747 250k 100'	MDW COROL Ctr
Actives	
N7TF L23 250k 110'	PLANO MDW Twr
IB449 747 220k 120'	ORD BEBEE Ctr
N6B C425 156k 50'	NILES PARK Twr
N231K PA46 134k 60'	DPA FARM Ctr
AA755 D10 250k 90'	ELGIN MDW Twr
N46ER C425 205k 60'	BOJAK YEARN Ctr
N627S L23 212k 100'	ORD Twr
N82R C425 170k 60'	LAIRD PLANO Ctr
N38G C425 250k 100'	DPA OBK Ctr
NW763 D10 250k 90'	MDW DEERE Ctr
N3K PA46 175k 100'	DEERE PLANO Ctr

Communications Score 5010
 App/Dep: NW763 heavy, Contact center. Good day.
 NW763 heavy: Switching to center frequency.
 App/Dep:

Figure A1 (Preceding Page). Static copy of TRACON® screen. There are three major components to the display. The right hand side of the screen shows Pending (not under control) and Active (under control) flight strips. Each flight strip lists (a) plane identifier, (b) plane type, (c) requested speed, (d) requested altitude, (e) Radar fix of sector entry, (f) Radar fix of sector exit (including Tower or Center). The lower part of the screen shows a communications box that gives a printout of the current (and last few) commands issued by the subject, and the responses from pilots or other controllers. The main part of the screen shows a radar representation of the Chicago sector. Planes are represented by a plane icon, and a data tag (which gives the identifier, the altitude, and an indication of current changes in altitude). The sector is bounded by the irregular dotted polygon describing a perimeter. Radar fixes are shown as small (+) figures on the radar screen. Airports are shown with approach cones, and a circle indicating the facility proper. A continuous radar sweep is shown (updating at 12 o'clock, every 5 sec). Range rings are also displayed, indicating 5 mile distances.

Task Controls and Knowledge of Results. Subjects interact with the TRACON simulation in several ways. A mouse is used for the majority of input activities, although the keyboard was also used alone, or in conjunction with the mouse. For each plane command, a menu of command choices is displayed on the screen. For turns (Left or Right), a small wheel was shown so that a direction was selected by pointing to the appropriate place on the wheel, and depressing the mouse key. Altitude and Speed commands resulted in the display of a small linear display from which the subject selected a particular value. Direct and Hold commands require the subject to move the mouse-cursor to a specific VOR fix or airport, and select a location. Resume and Handoff commands have no additional menus, but are initiated directly.

Additional commands for information (Flight Path, Plane Type, and Plane Current Heading (in degrees) and Airspeed (in knots) may also be obtained. Information pertaining to the sector constraints (Map of VOR/Airport fixes; and Airport Information, including final approach heading and altitude requirements) may be called up with keyboard commands.

Knowledge of results is provided visually (by text in the communications box) and auditorially with a read-back by the pilot or other controller (using digitized speech broadcast over the subject's headset). If a command is not allowed (e.g., asking a pilot to increase or decrease speed beyond the limitations imposed by the type of plane), the visual and auditory response indicated a failure to comply with the command (e.g., "Sorry, but that is below my 'stall' speed!"). Handoff commands differ from the other commands, in that a handoff to another sector is only accepted when the plane is within 5 miles of the sector boundary. All other requests for handoff are refused by Center Controllers.

In addition, planes follow (as nearly as possible) the commands issued by the subject. Turn, altitude change, and speed change commands are processed by the computer, and are carried out in accordance with the limitations imposed by each aircraft type (e.g., smaller planes turned in a smaller radius than Boeing 747's, but 747's climbed more quickly than the smaller planes). Each plane performs within the constraints that were displayed when a subject calls up the information for that plane type.

Finally, when errors occur (e.g., separation conflicts, near misses, crashes, missed approaches, handoff errors), additional information is presented to the subject. In each of these cases, an alert circle around the plane(s) in question is presented on the screen, and a series of tones are presented over the headset. If two planes crash, a message appeared on the screen indicating which of the planes crashed. (In normal training, the simulation is immediately halted under such conditions. However, because it is not desirable to minimize learning opportunities of subjects who have crashes, the simulation continues under such circumstances.)

Points. Subjects are told to perform the task so that they maximize successful disposition of all flight paths, but that safety is a critical component of the task. Points are given for successful accomplishment of each plane's flight plan, and penalty points are deducted for both commission or omission errors. Points assigned are based on a priori judgements of task component difficulty (e.g., arrivals were more difficult to accomplish than overflights, so arrivals received three times as many points). The point assignments are used

to encourage subjects to develop an appropriate strategy for task component emphasis.

Trial Description Trials for the task are created and pretested to be roughly equivalent in difficulty. Each trial contains planes that are divided into three basic categories (Overflights, Departures, and Arrivals). Overflights are planes that enter and exit the subject's airspace at cruising altitudes. Subjects are required to acknowledge these airplanes as they approach a boundary VOR fix, monitor progress through the sector, and handoff to a "Center" controller. Departures are planes that originate at one of the four airports, climb to a cruising altitude and are handed off to a "Center" controller. Subjects are required to release departures from airports, evaluate and remediate potential conflicts as the planes climb to a cruising altitude and turn to intercept their intended flight paths, and then handoff planes to the appropriate Center controller. Arrivals enter the subject's airspace from one of the boundary VOR fixes, and have to be landed at a designated airport. Subjects are required to direct arrivals onto an appropriate heading and altitude to provide an acceptable handoff to the appropriate Tower controller, then these planes can land. Practice flights, which originate at an airport, but have to be correctly vectored to be landed again at the same airport are classified as "Arrivals," because demands of these flights are most similar to other arrivals. For all flights, the subject is required to maintain legal separation (at least 1000 ft in altitude, or 3 mi horizontally).

A successful "handle" of a flight is the appropriate accomplishment of the respective flight plan. That is, for a departure or an overflight, the accomplishment was a successful handoff to the appropriate Center controller. For a landing, the accomplishment was the successful landing of the airplane.

Errors in performance take a variety of different forms, as follows: (1) Incorrect speed or altitude for center handoff; (2) A failure to handoff the plane; (3) For arrival flights, errors include "wrong approach altitude," or "wrong approach heading" (which requires the subject to reorient the plane for another landing attempt); and (4) Separation conflicts, near misses, and crashes (for a differing degrees of airspace proximity violations).

Performance Measures. After extensive review of the raw data from initial experiments (which include every command issued by subjects during TRACON trials, and a series of summary data for each airplane in a simulation, and for each simulation overall), a general criterion of merit has been selected that reflected overall task performance. This measure, called "Overall Performance" is computed as the sum of all flights accepted into the sector that have a final disposition within the simulation time (minus any planes that are incorrectly disposed of -- e.g., crashes, not-handed-off, vectored off the radar screen). This measure is generally concordant with results from the examination of the criterion space for FAA ATC simulation research (e.g., see Buckley, DeBaryshe, Hitchner, & Kohn, 1983). Other measures are also computed, to reflect declarative knowledge (information requests) and task component processing (separate scores for number of arrivals, departures, and overflights accepted into the sector).